Standard Radiometers and Targets for Microwave Remote Sensing

J. Randa, A. E. Cox, D.K. Walker,
M. Francis, J. Guerrieri, and K. MacReynolds

Electromagnetics Division
National Institute of Standards and Technology
Boulder, Colorado

IGARSS, Anchorage, 9/21/04

INTRODUCTION

- NIST microwave radiometry effort
  - Noise & antenna metrology have been conducted separately for over 30 years
  - Recently began doing remote-sensing radiometry, combining the two
- NIST Optical Tech. Div. has such a program for UV, Visible, & IR
- Developing analogous capabilities at microwave & mm-wave frequencies, providing a link between microwave remote-sensing measurements & NIST measurements & standards

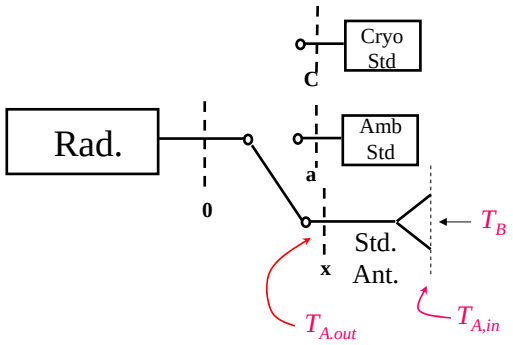
- Calibration
  - linear radiometers ⇒ need (≥) two standards for calibration
  - need independent cal of targets, comparison to other radiometers, traceability
- Develop (& transfer) a standard for microwave brightness temperature
- Still in early stages, but some progress made

THEORETICAL FRAMEWORK

- Standard radiometer
- Brightness temperature
- Chamber
- Expected uncertainty

Standard Radiometer

- Radiometer measures $T_{A,out}$; want to determine T_B (assume far field conditions)



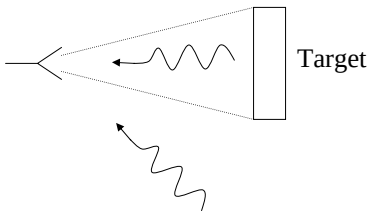
$$T_{A,out} = \alpha T_{A,in} + (1-\alpha)T_a$$

$$T_B(\theta,\phi) \equiv \frac{\lambda^2 B_f(\theta,\phi)}{2k}$$

$$T_{A,in} = \frac{\int_{4\pi} T_B(\theta,\phi)F_n(\theta,\phi)d\Omega}{\Omega_p}$$

$$\Omega_p = \int_{4\pi} F_n(\theta,\phi)d\Omega$$

Break up $T_{A,in}$:



$$\overline{T_T} = \frac{\int_{\text{target}} T_B(\theta,\phi)F_n(\theta,\phi)d\Omega}{\int_{\text{target}} F_n(\theta,\phi)d\Omega}$$

$$\overline{T_{BG}} = \frac{\int_{\text{other}} T_B(\theta,\phi)F_n(\theta,\phi)d\Omega}{\int_{\text{other}} F_n(\theta,\phi)d\Omega} .$$

$$\eta_{AT} \equiv \frac{\int_{\text{target}} F_n(\theta,\phi)d\Omega}{\Omega_p}$$

$$T_{A,in} = \eta_{AT}\overline{T_T} + (1-\eta_{AT})\overline{T_{BG}}$$

- So,

$$T_{A,out} = \alpha\eta_{AT}\overline{T}_T + \alpha(1-\eta_{AT})\overline{T}_{BG} + (1-\alpha)T_a$$

- Control the background, $\overline{T}_{BG} = T_a$
- Then

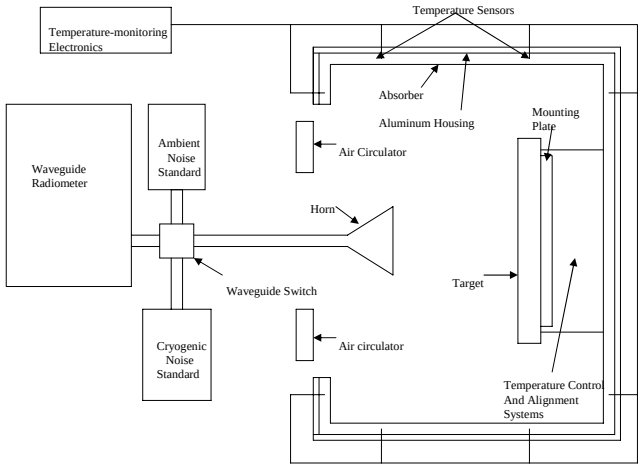
$$\overline{T}_T = T_a + \frac{1}{\alpha\eta_{AT}}\left(T_{A,out} - T_a\right)$$

- So we need $\alpha \approx 1/L$ and η_{AT}

$$\eta_{AT} \equiv \frac{\int_{\text{target}} F_n(\theta,\phi)d\Omega}{\Omega_p}$$

Chamber

- Will need a chamber to control background



Uncertainties

- Approximate achievable uncertainties:

$$u^2(\bar{T}_T) = \left(1 - \frac{1}{\alpha\eta_{AT}}\right)^2 u^2(T_a) + \left(\frac{1}{\alpha\eta_{AT}}\right)^2 u^2(T_{A,out}) + (\bar{T}_T - T_a)^2 \left(\frac{u^2(\eta_{AT})}{\eta_{AT}^2} + \frac{u^2(\alpha)}{\alpha^2}\right)$$

$u(T_a) \approx 0.2$ K

$u(T_{A,out}) \approx 0.3 - 0.5$ K (for $T_{A,out}$ = 200 to 300 K, 18 – 26.5 GHz)

$u(\eta_{AT}) \approx 0.003$

$u(\alpha) \approx 0.005$

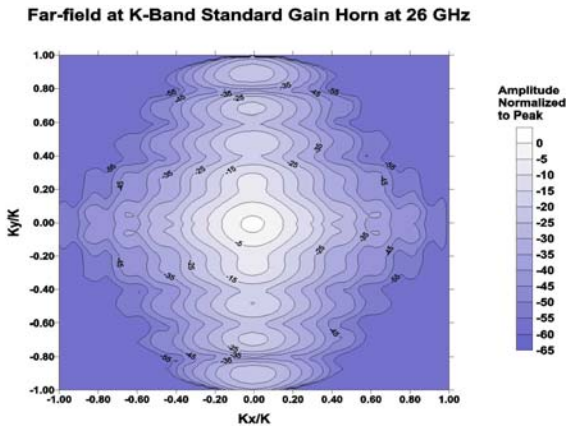
- So should be able to get

$u(\bar{T}_T) \approx 0.3$ K to 0.7 K

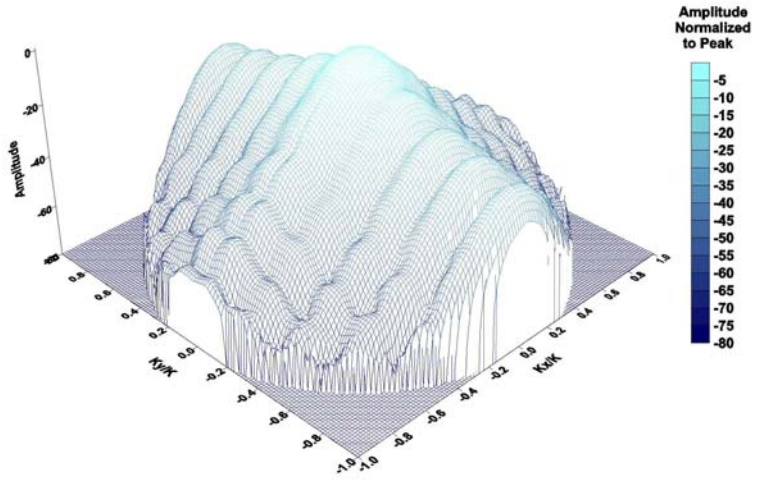
for $T_{A,out}$ = 200 to 300 K, 18 – 26.5 GHz

MEASUREMENTS (PRELIMINARY)

- Measured antenna pattern for a standard-gain horn (SGH) on the near-field range

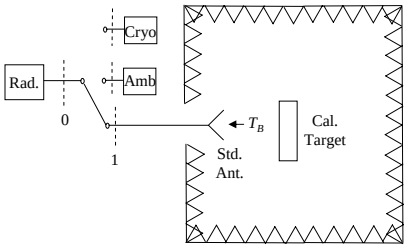


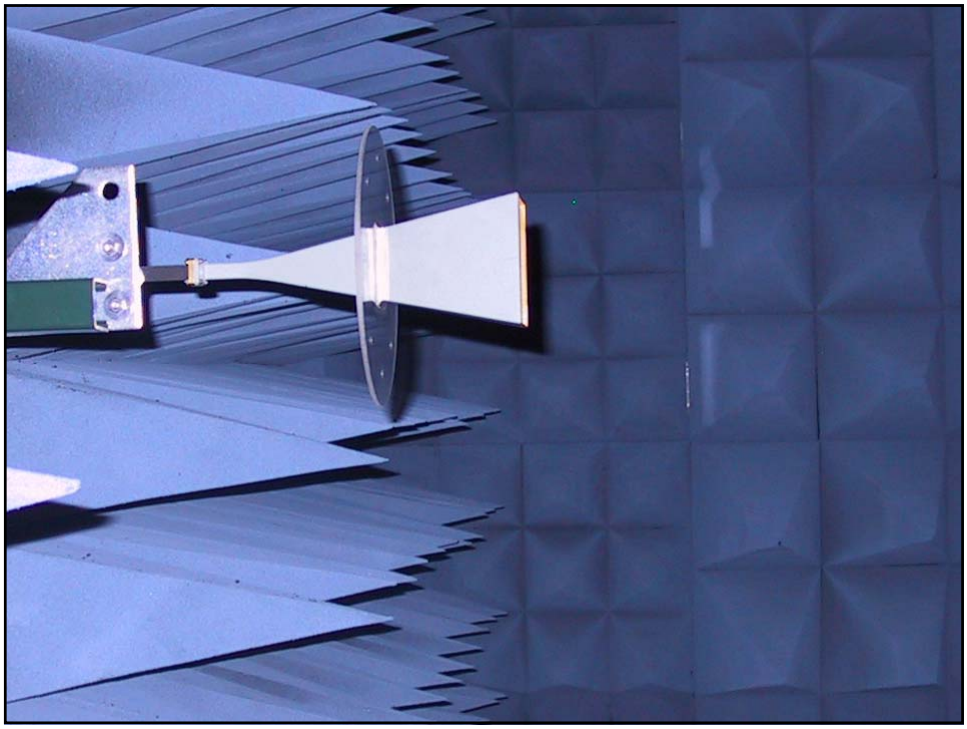
Far-field at K-Band Standard Gain Horn at 26 GHz

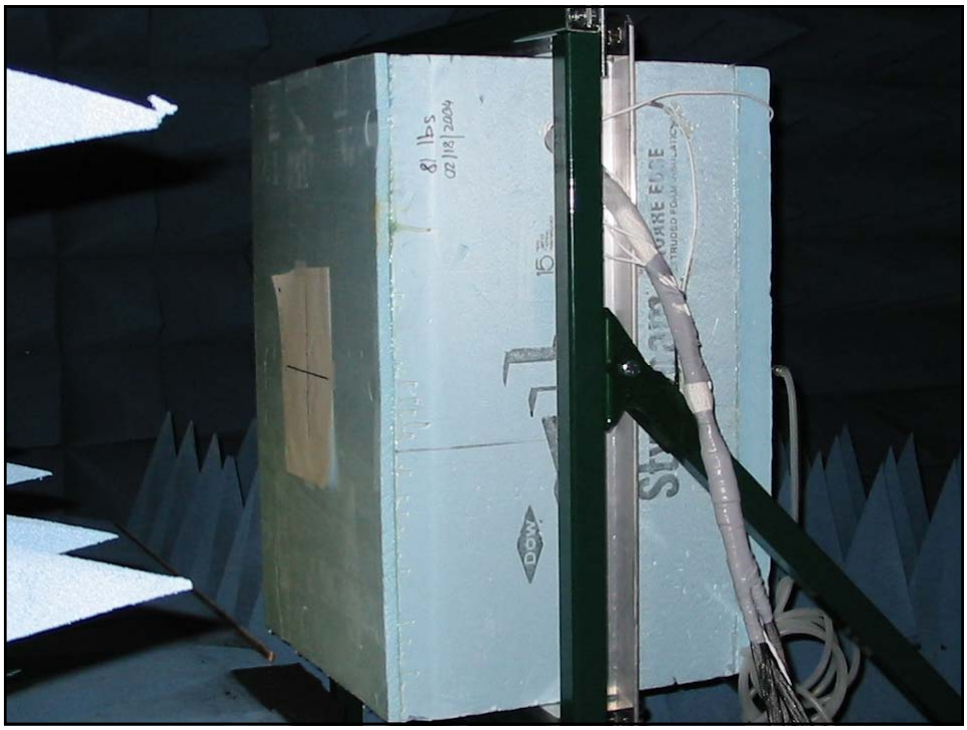


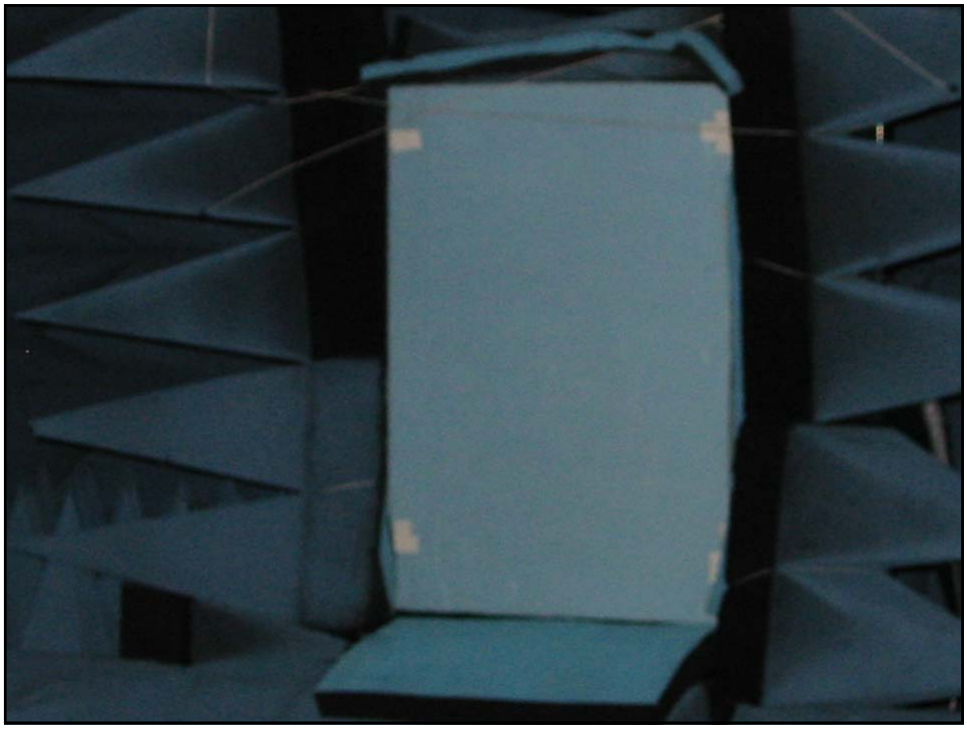
- Integrate pattern to get η_{AT}; value depends on frequency & distance. At 26 GHz, η_{AT} = 0.980 at 50 cm, η_{AT} = 0.301 at 5 m
- Compute α from conductivity. $\alpha = 0.9954 \pm 0.0023$ at 26 GHz
- Connected SGH to the DUT plane of the WR-42 (18 – 26.5 GHz) waveguide radiometer

- Borrowed hot calibration targets from NOAA GSR (Al Gasiewski & Marian Klein, NOAA ETL) and NASA Goddard (Paul Racette)
- Measured it in the NIST anechoic chamber at 18, 22, & 26 GHz for several distances

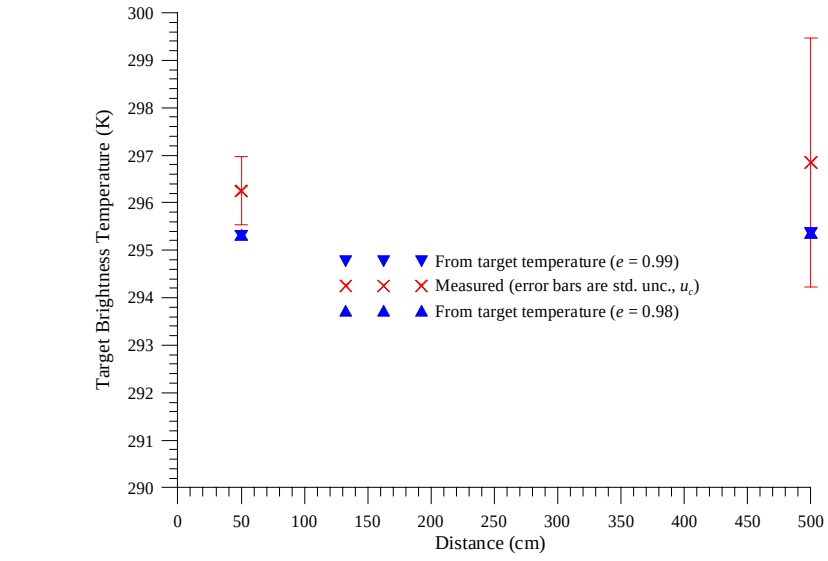


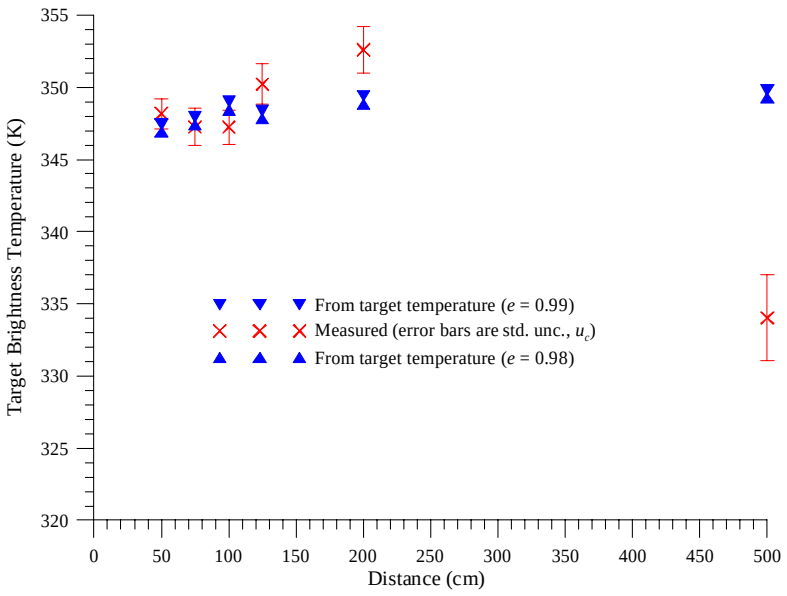



DOW

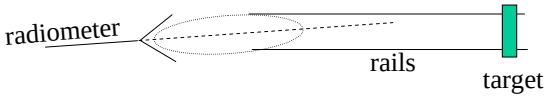


Results

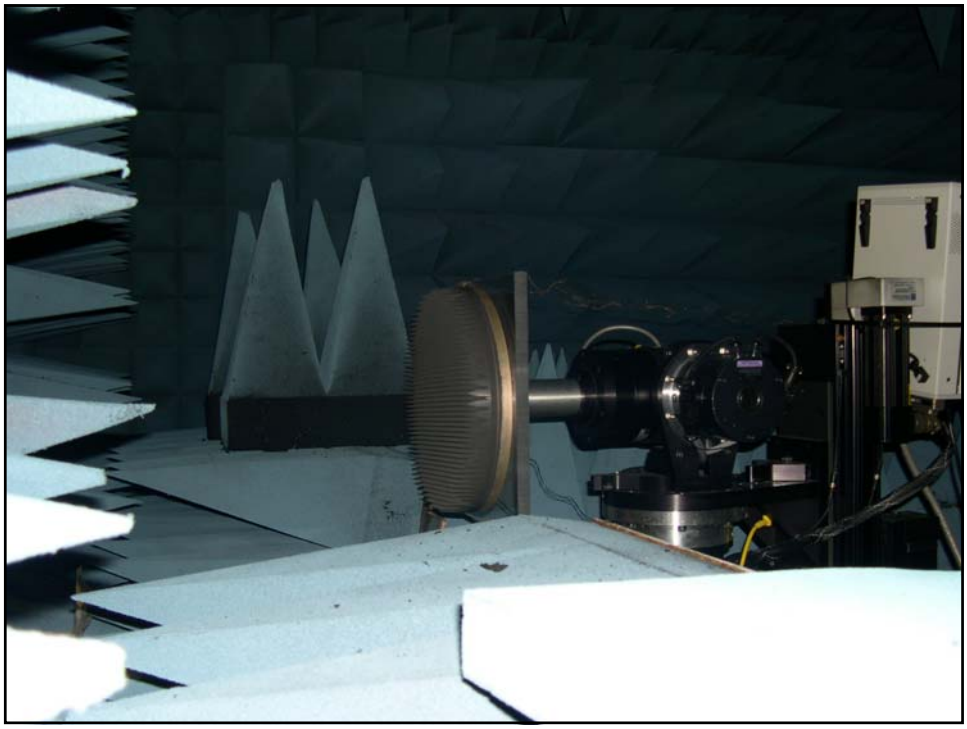

Target Brightness Temperature (K)
300
299
298
297
296
295
294
293
292
291
290
0
50
100
150
200
250
300
350
400
450
500
Distance (cm)
From target temperature (e = 0.99)
Measured (error bars are std. unc., u_c)
From target temperature (e = 0.98)



- 5 m results discrepancy probably just due to (mis)alignment



- Uncertainty large due to large $u(\eta_{AT})$ = 0.0153. Would be $u(\eta_{AT}) \approx 0.003$ if we knew target location better



Issues

- Type A uncertainties (target drift)
- Target location & angles
- Alignment of radiometer & target
- Near/Far field
- Emissivity: $T_T = eT_{target} + (1 - e)T_{refl}$, e = ?

SUMMARY

- Developing a microwave (18 – 65 GHz) brightness-temperature standard based on existing noise standards and radiometers, plus antenna characterization
- Have developed framework and performed preliminary measurements
- Expect uncertainties of about 0.5 – 0.7 K for T_B = 200 to 300 K, f = 18 – 26 GHz (Larger uncerts for higher/lower temperatures and/or higher frequencies)

- Next:
  - Further preliminary measurements (different target)
  - Design & build special-purpose chamber
  - Measurements in special-purpose chamber
  - Measurements of a target in the IR using TXR radiometer
  - Develop standard target